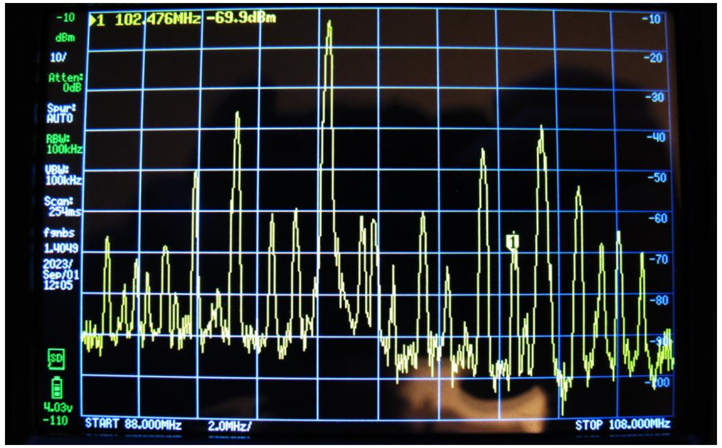
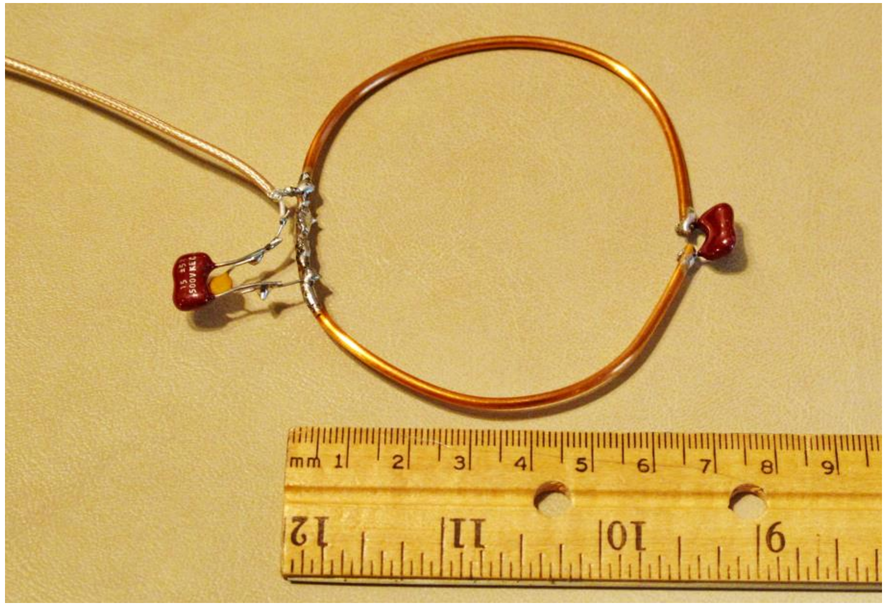
Antenna Briefs #9 -- Small Loop Antennas for FM / VHF / UHF Radio Receivers

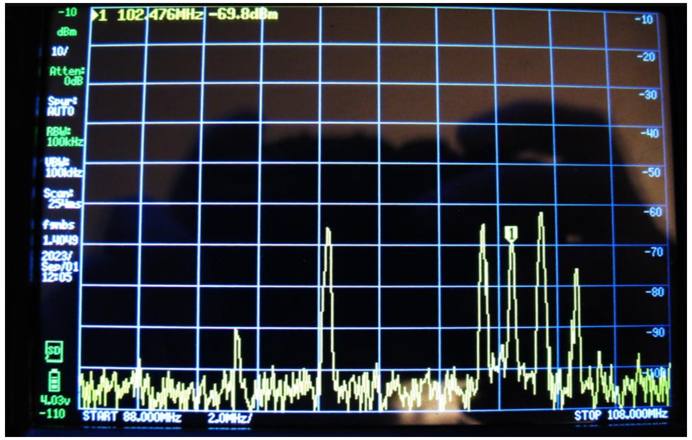
Slides downloaded from: https://ecefiles.org/rf-design/

Companion video at: https://www.youtube.com/watch?v=BjI8g12_a00

A fairly in-depth look at using highly frequency-selective, small-loop antennas to create improved radio receivers. Prototypes and demonstrations focus on the FM broadcast band, but the techniques are general. Topics include design motivations, the evolution of the "FM Tiny Loop" antenna from a ham-radio / shortwave HF small loop, and a brief overview of the theory of operation.



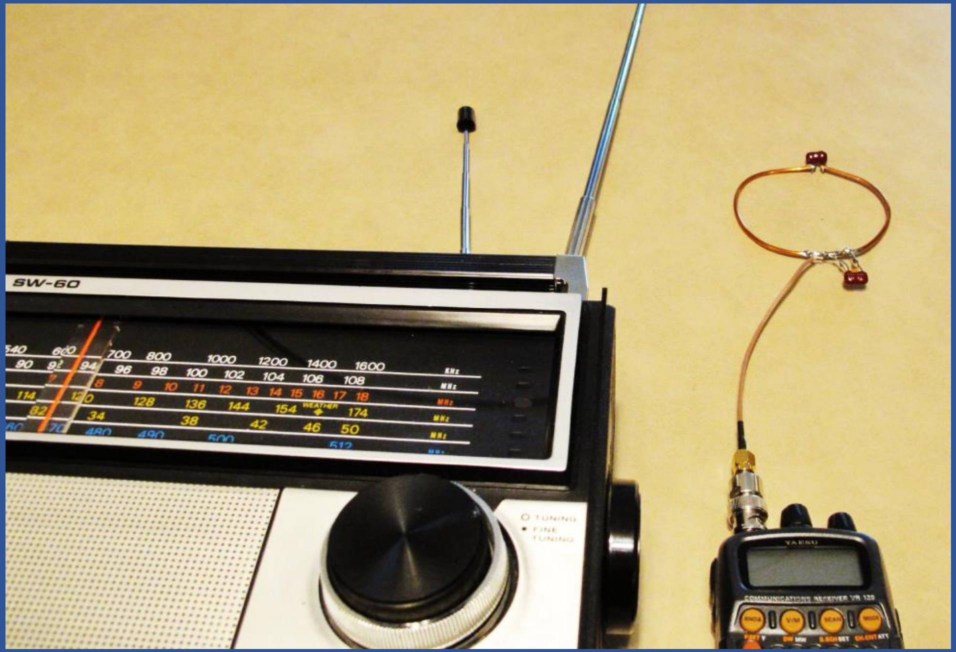


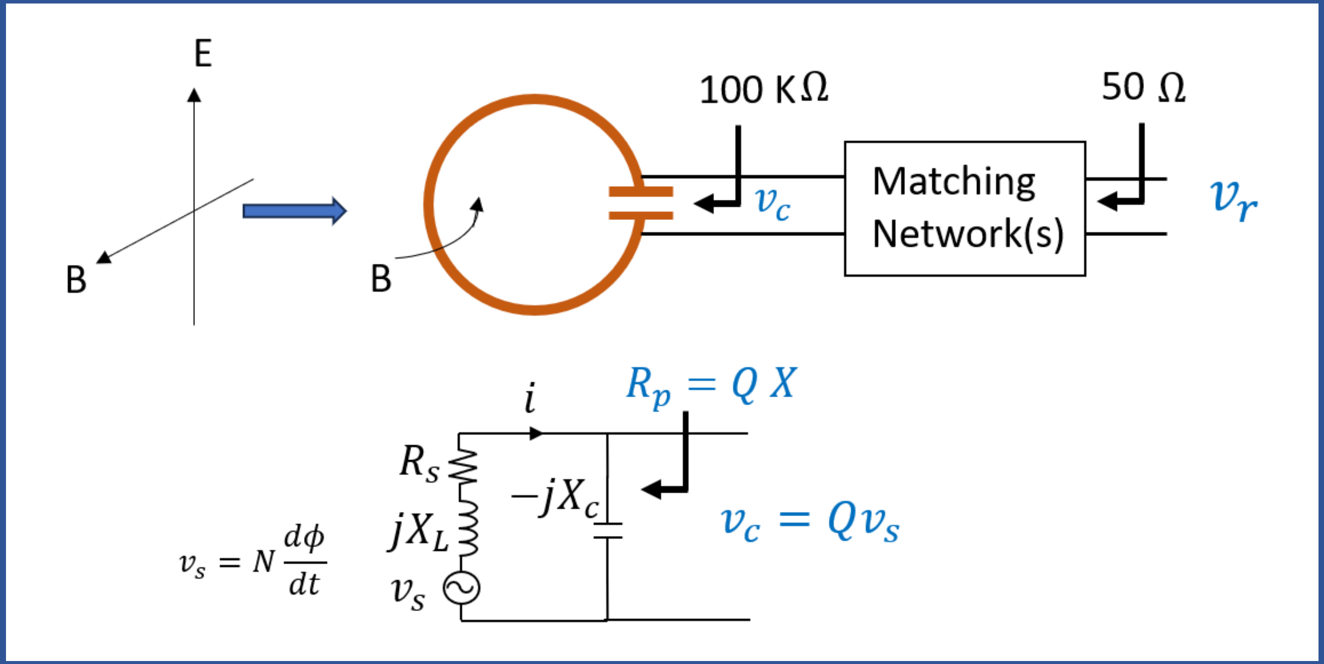


Antenna Briefs #9

Designing Small Loop Antennas

For FM / VHF / UHF Radio Receivers



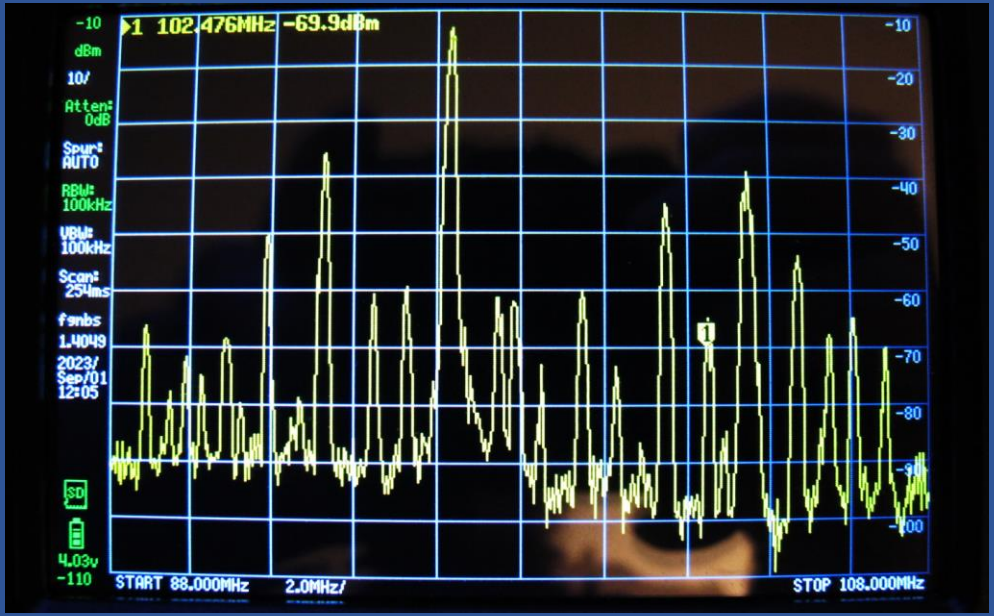


Monopole/Dipole vs Small Loop

FM Broadcast band reception in suburban area

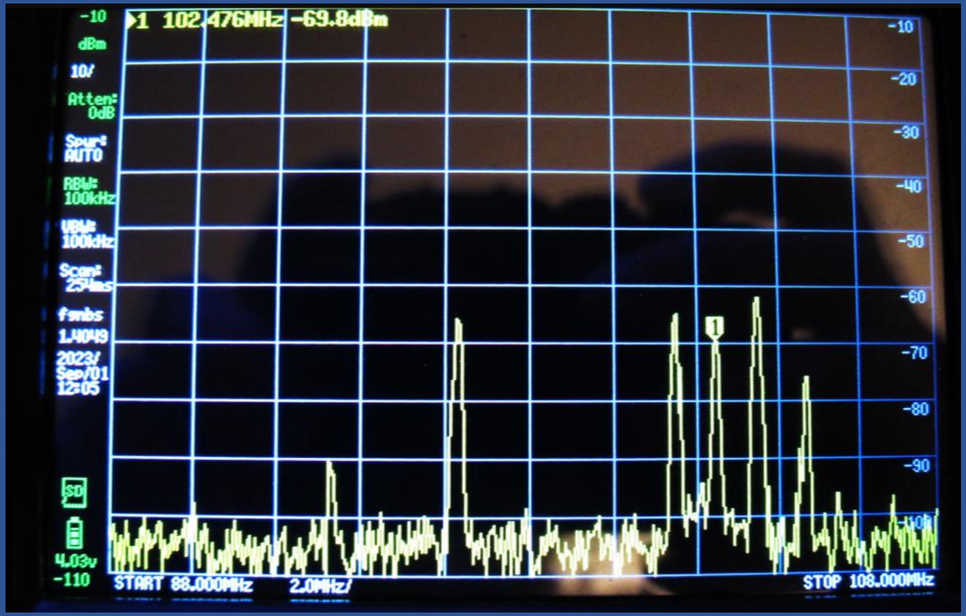
88 to 108 MHz horizontal, 10 dB/div vertical, Ref Level -10 dBm

Using half-wave (1.5 m) vertical dipole



SIR = 55 dB at Marker 1

Using 7 cm diameter loop
20x smaller !



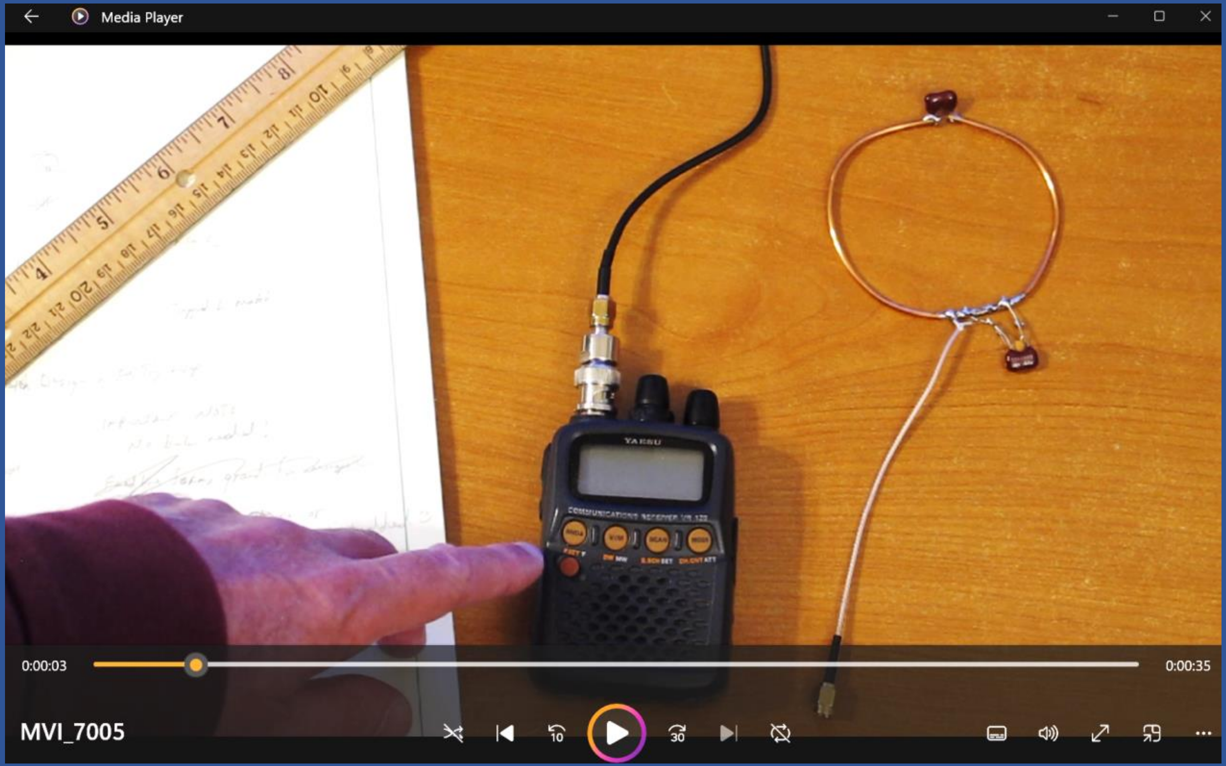
<u>SIR now 3</u> <u>dB</u> at Marker 1

ECEFILES.ORG

Demo: Dipole vs Small Loop

FM Broadcast band reception in suburban area

Yaesu VR-120 Wideband Receiver at 102.5 FM



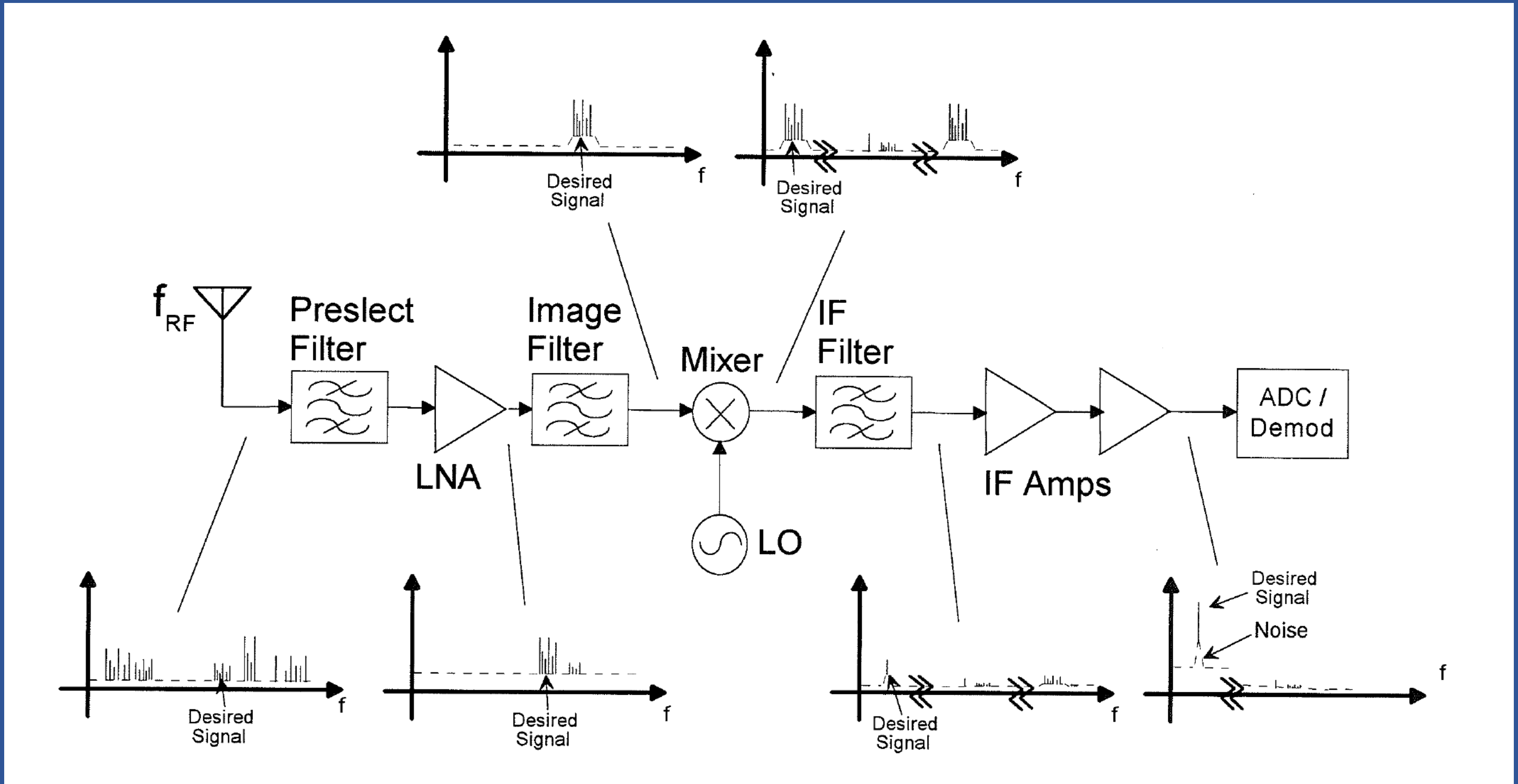
ECEFILES.ORG

Today's Episode

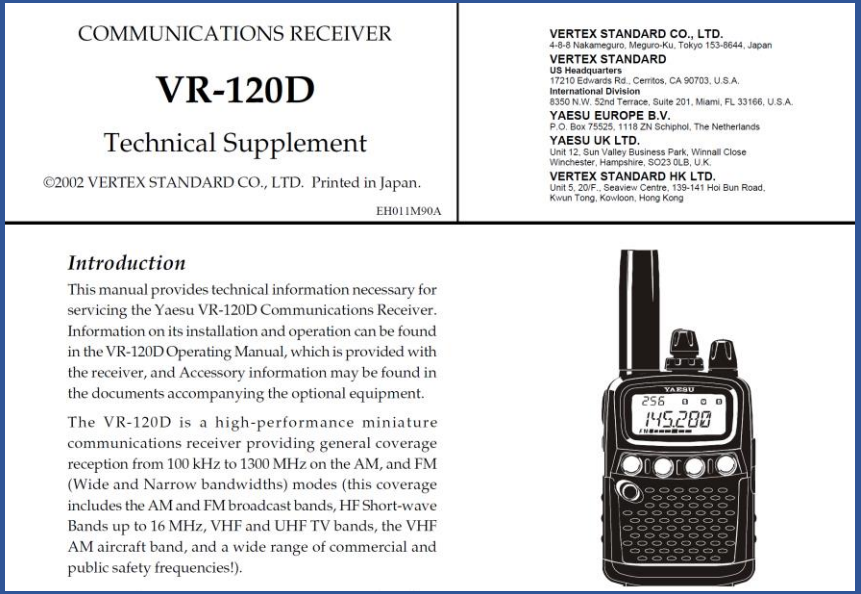
Topics

→ • Introduction
- Design motivations
- Evolution of the "FM Tiny Loop" design
- Advantages and Disadvantages
- Brief theory of operation
- Summary and future directions ...

Classic Superhet Receiver Block Diagram
(from Radio Design 101 series)



VR-120 Block Diagram



COMMUNICATIONS RECEIVER

VR-120D

Technical Supplement

©2002 VERTEX STANDARD CO., LTD. Printed in Japan.

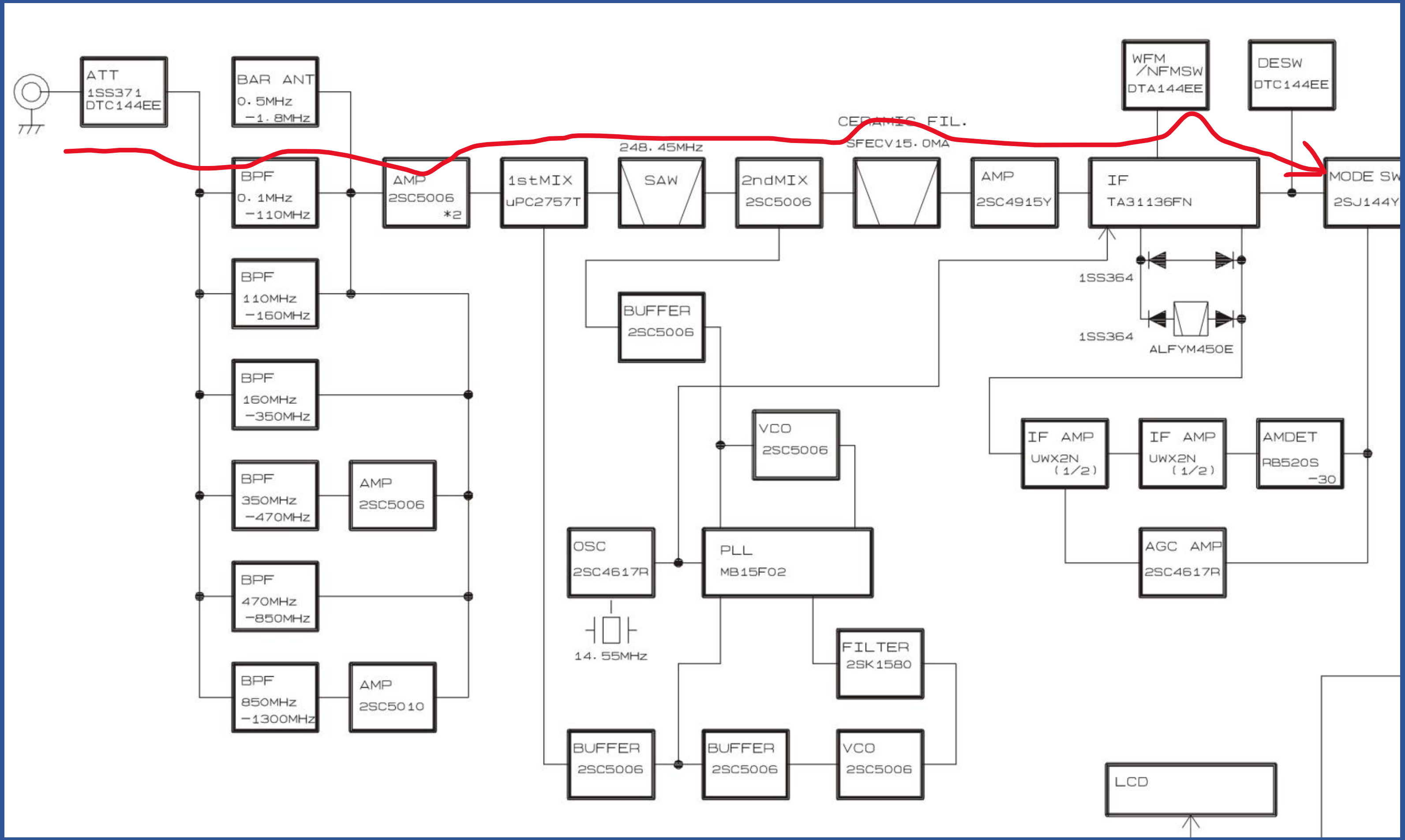
EH011M90A

VERTEX STANDARD CO., LTD.
4-8-8 Nakameguro, Meguro-Ku, Tokyo 153-8644, Japan
VERTEX STANDARD
US Headquarters
17210 Edwards Rd., Cerritos, CA 90703, U.S.A.
International Division
8350 N.W. 52nd Terrace, Suite 201, Miami, FL 33166, U.S.A.
YAESU EUROPE B.V.
P.O. Box 75525, 1118 ZN Schiphol, The Netherlands
YAESU UK LTD.
Unit 12, Sun Valley Business Park, Winnall Close
Winchester, Hampshire, SO23 0LB, U.K.
VERTEX STANDARD HK LTD.
Unit 5, 20/F., Seaview Centre, 139-141 Hoi Bun Road,
Kwun Tong, Kowloon, Hong Kong

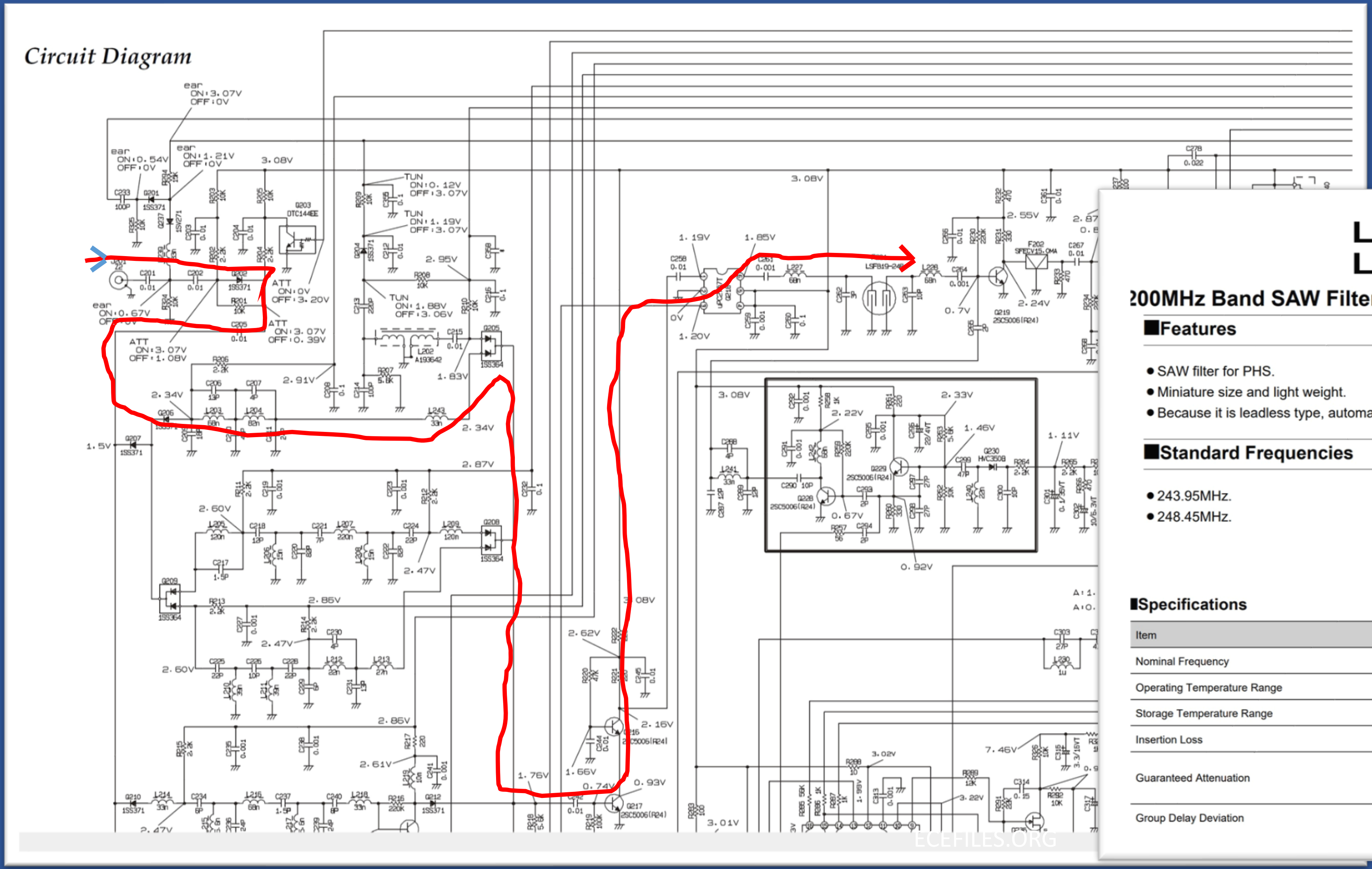
Introduction

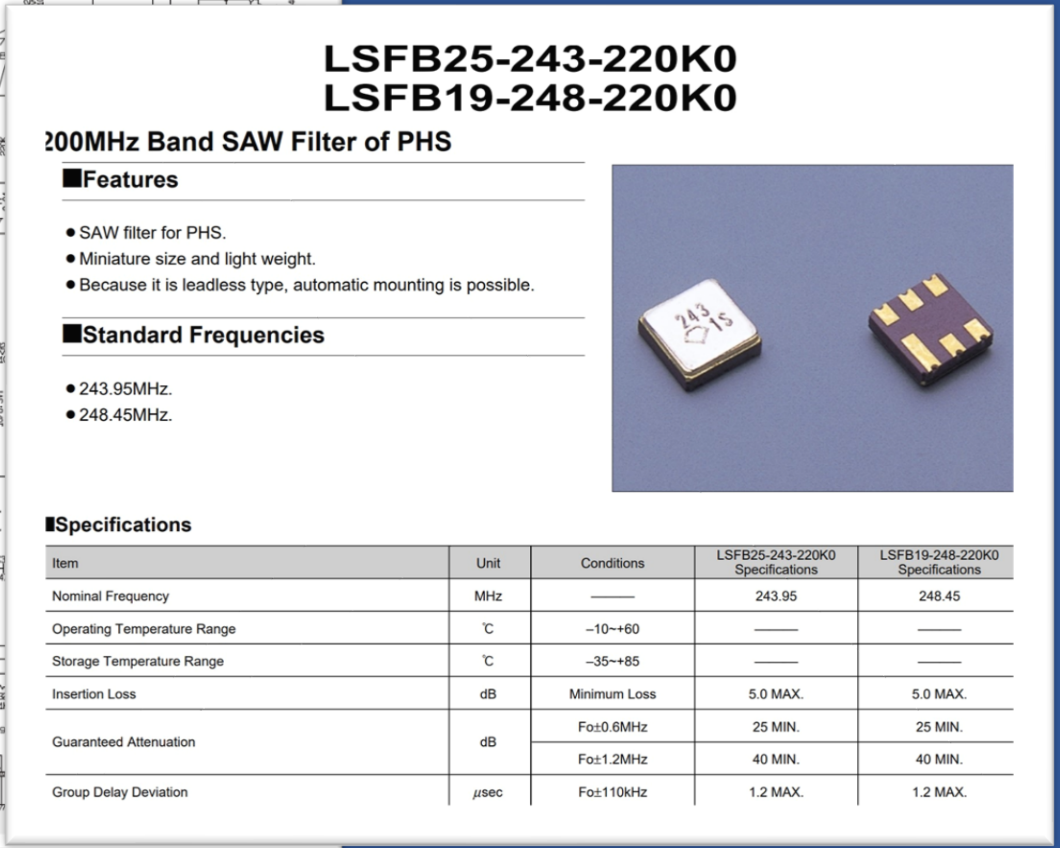
This manual provides technical information necessary for servicing the Yaesu VR-120D Communications Receiver. Information on its installation and operation can be found in the VR-120D Operating Manual, which is provided with the receiver, and Accessory information may be found in the documents accompanying the optional equipment.

The VR-120D is a high-performance miniature communications receiver providing general coverage reception from 100 kHz to 1300 MHz on the AM, and FM (Wide and Narrow bandwidths) modes (this coverage includes the AM and FM broadcast bands, HF Short-wave Bands up to 16 MHz, VHF and UHF TV bands, the VHF AM aircraft band, and a wide range of commercial and public safety frequencies!).



Minimal Filtering at RF





LSFB25-243-220K0
LSFB19-248-220K0

200MHz Band SAW Filter of PHS

■Features

- SAW filter for PHS.
- Miniature size and light weight.
- Because it is leadless type, automatic mounting is possible.

■Standard Frequencies

- 243.95MHz.
- 248.45MHz.

■Specifications

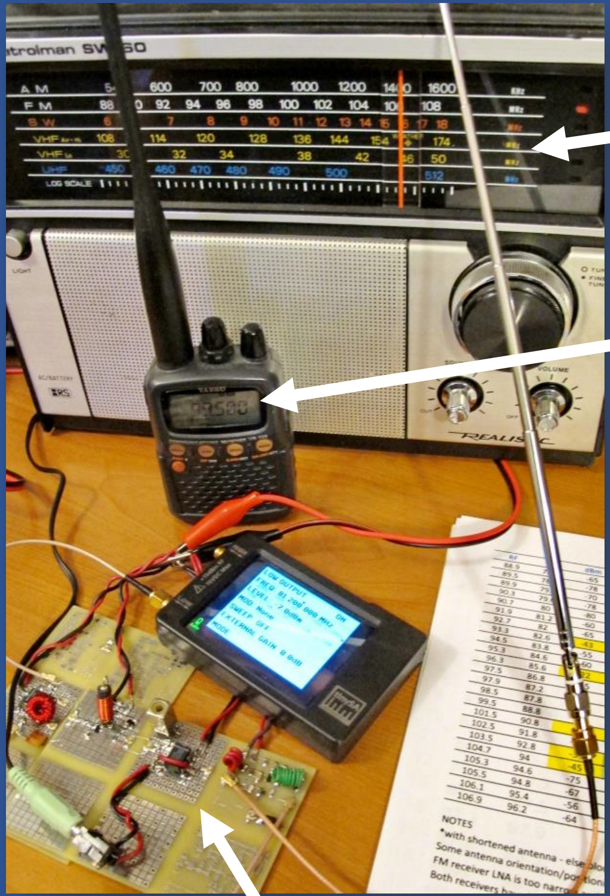
Item	Unit	Conditions	LSFB25-243-220K0 Specifications	LSFB19-248-220K0 Specifications
Nominal Frequency	MHz	———	243.95	248.45
Operating Temperature Range	℃	–10~+60	———	———
Storage Temperature Range	℃	–35~+85	———	———
Insertion Loss	dB	Minimum Loss	5.0 MAX.	5.0 MAX.
Guaranteed Attenuation	dB	Fo±0.6MHz	25 MIN.	25 MIN.
		Fo±1.2MHz	40 MIN.	40 MIN.
Group Delay Deviation	μsec	Fo±110kHz	1.2 MAX.	1.2 MAX.

Today's Episode

Topics

- Introduction
- → Design motivations
- Evolution of the "FM Tiny Loop" design
- Advantages and Disadvantages
- Brief theory of operation
- Summary and future directions …

Comparing Four Radios, using Monopoles



1990 Portable multi-band (Patrolman SW-60)

2003 Commercial wideband handheld (VR-120)

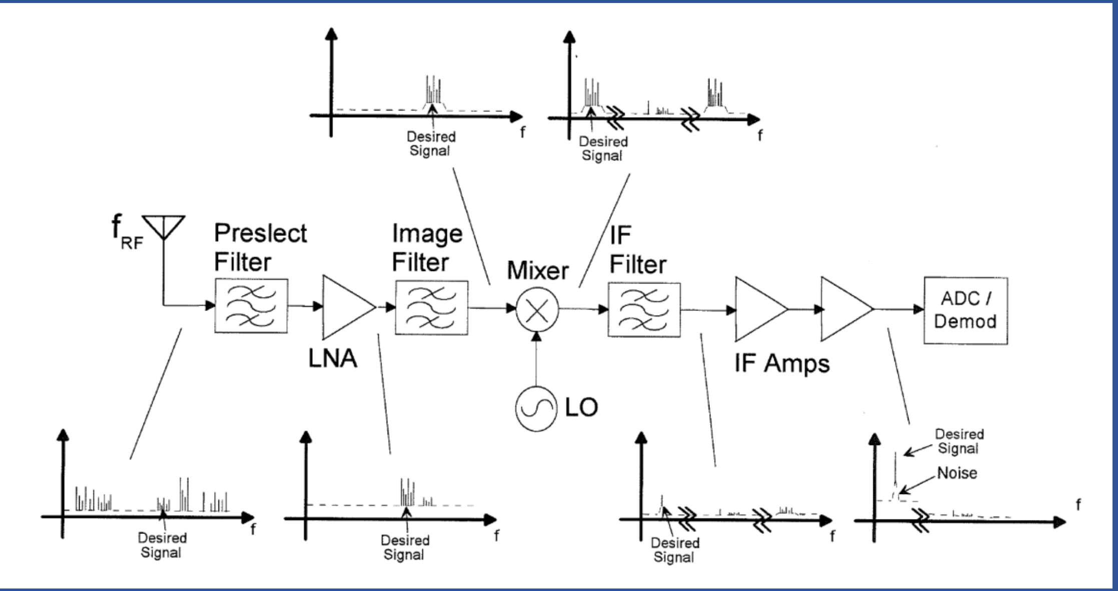
2022 Homebrew FM classic superhet (RD-101)

2021 Software-Defined Radio (ATS-25)

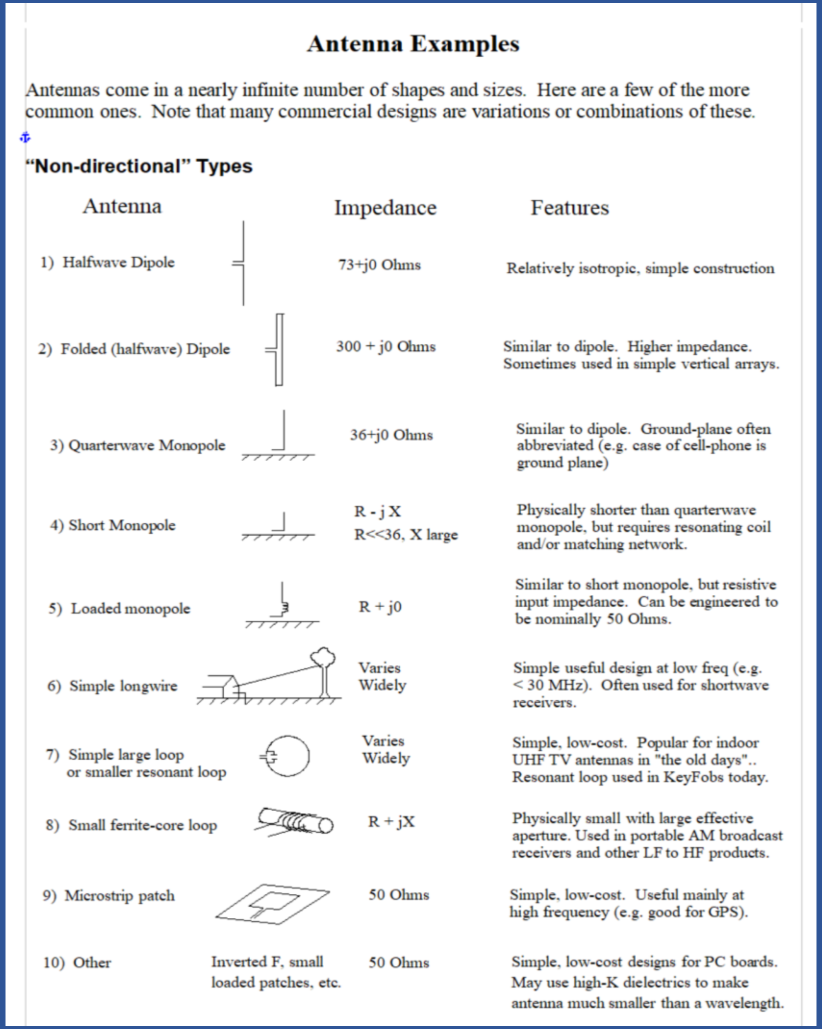
Station	dBm	ATS 25	VR-120	SW-60	RD-101*
88.1	-96				
88.9	-58				
89.5	-75				
89.9	-61				
90.3	-77				
90.5	-85				
90.7	-71				
91.3	-80				
91.9	-55				
92.5	-82				TBD
92.7	-70				|
93.3	-41				|
94.5	-63				V
95.3	-60				
96.3	-24				
97.5	-80				
97.9	-66				

The Bigger Picture

- Radio bands becoming increasingly crowded
- Historic emphasis on noise figure and image rejection is not sufficient
- Too little emphasis placed on strong-signal handling, especially in-band …
- Regulatory agencies (e.g. FCC in the US) beginning to recognize the need to qualify receivers as well as transmitters
- Filtering with sufficiently high "Q" is hard
- Frequency selective antennas could be part of the solution ?



Antenna Options

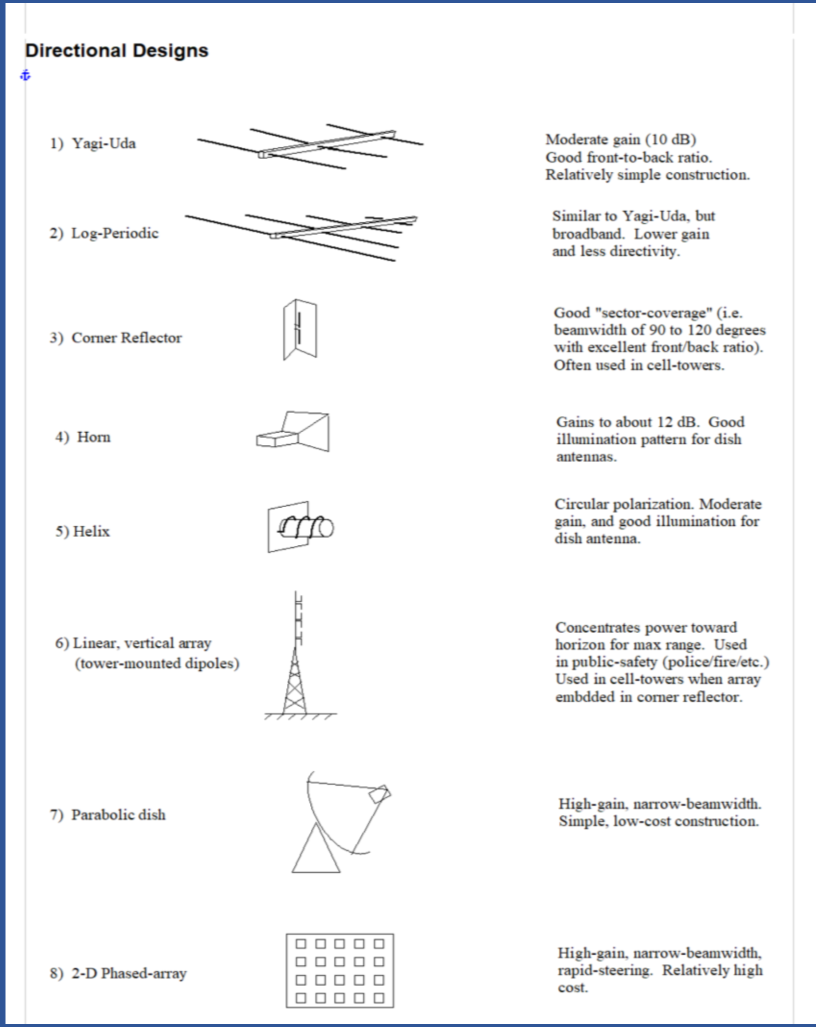


Antenna Examples

Antennas come in a nearly infinite number of shapes and sizes. Here are a few of the more common ones. Note that many commercial designs are variations or combinations of these.

"Non-directional" Types

Antenna	Impedance	Features
1) Halfwave Dipole	73+j0 Ohms	Relatively isotropic, simple construction
2) Folded (halfwave) Dipole	300 + j0 Ohms	Similar to dipole. Higher impedance. Sometimes used in simple vertical arrays.
3) Quarterwave Monopole	36+j0 Ohms	Similar to dipole. Ground-plane often abbreviated (e.g. case of cell-phone is ground plane)
4) Short Monopole	R - j X R<<36, X large	Physically shorter than quarterwave monopole, but requires resonating coil and/or matching network.
5) Loaded monopole	R + j0	Similar to short monopole, but resistive input impedance. Can be engineered to be nominally 50 Ohms.
6) Simple longwire	Varies Widely	Simple useful design at low freq (e.g. < 30 MHz). Often used for shortwave receivers.
7) Simple large loop or smaller resonant loop	Varies Widely	Simple, low-cost. Popular for indoor UHF TV antennas in "the old days".. Resonant loop used in KeyFobs today.
8) Small ferrite-core loop	R + jX	Physically small with large effective aperture. Used in portable AM broadcast receivers and other LF to HF products.
9) Microstrip patch	50 Ohms	Simple, low-cost. Useful mainly at high frequency (e.g. good for GPS).
10) Other — Inverted F, small loaded patches, etc.	50 Ohms	Simple, low-cost designs for PC boards. May use high-K dielectrics to make antenna much smaller than a wavelength.



Directional Designs

Antenna	Features
1) Yagi-Uda	Moderate gain (10 dB) Good front-to-back ratio. Relatively simple construction.
2) Log-Periodic	Similar to Yagi-Uda, but broadband. Lower gain and less directivity.
3) Corner Reflector	Good "sector-coverage" (i.e. beamwidth of 90 to 120 degrees with excellent front/back ratio). Often used in cell-towers.
4) Horn	Gains to about 12 dB. Good illumination pattern for dish antennas.
5) Helix	Circular polarization. Moderate gain, and good illumination for dish antenna.
6) Linear, vertical array (tower-mounted dipoles)	Concentrates power toward horizon for max range. Used in public-safety (police/fire/etc.) Used in cell-towers when array embdded in corner reflector.
7) Parabolic dish	High-gain, narrow-beamwidth. Simple, low-cost construction.
8) 2-D Phased-array	High-gain, narrow-beamwidth, rapid-steering. Relatively high cost.

Receiver Design Options

(For details, see: Radio Design 101, Epilogue 3)

- Strong-signal interferers create blocking and intermod problems in receiver circuits ! Interferers can be out-of-band, or **in-band (OOB/IB**)
- Traditional solutions
  - Preselect (and image) filtering for OOB interferers
  - RF (and IF) gain control using attenuators/AGC
  - Higher power consumption in circuits to improve compression and intermodulation performance
  - **Selective antennas (e.g. directional designs)**
- Tracking front-end filters generally provide best performance if low power is needed (but are difficult to integrate on-chip)
- Small Loop antennas can address OOB **and IB** interference !

Today's Episode

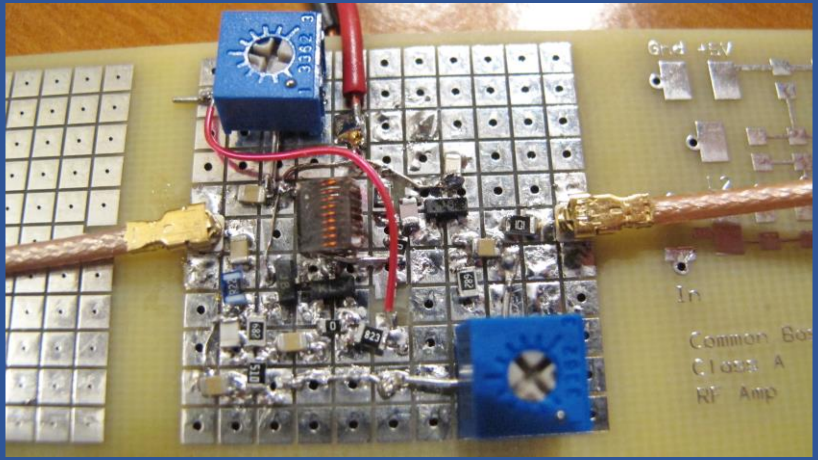
Topics

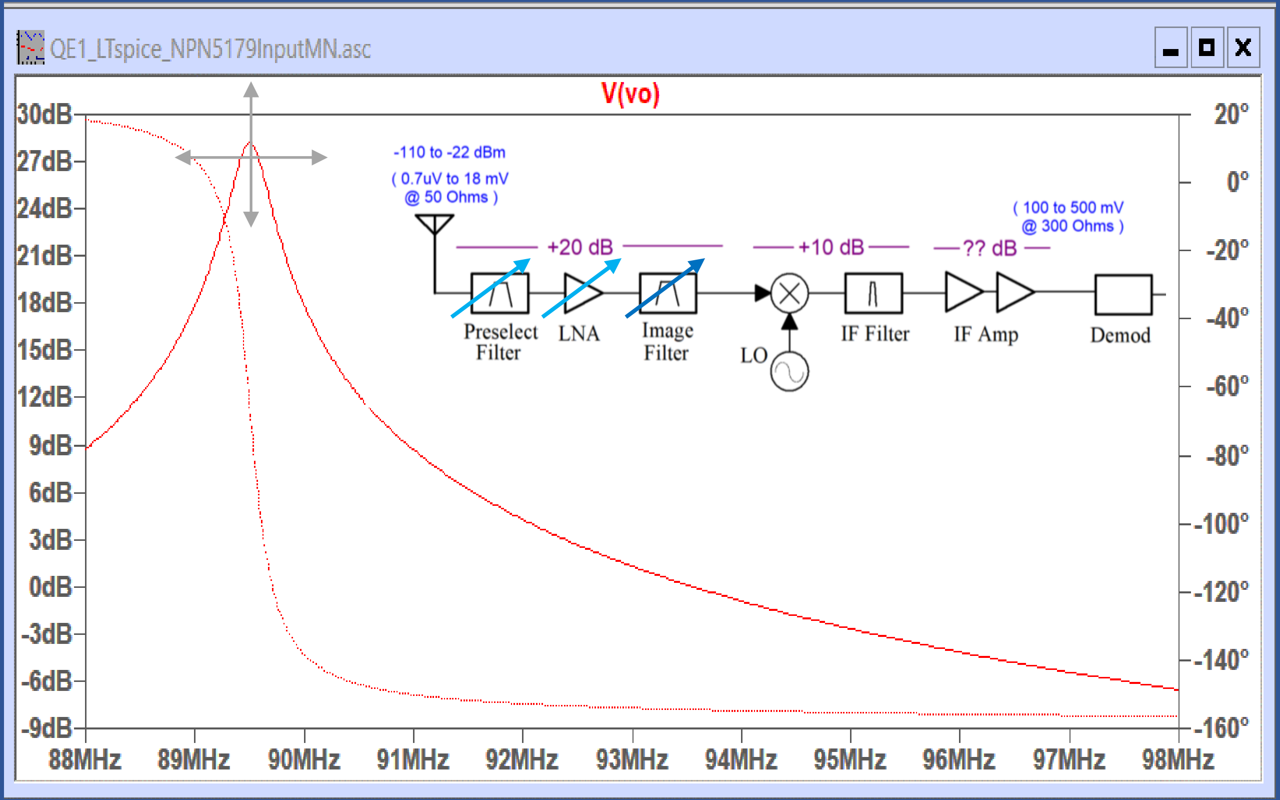
- Introduction
- Design motivations
- → Evolution of the "FM Tiny Loop" design
- Advantages and Disadvantages
- Brief theory of operation
- Summary and future directions …

High Q Filtering and RX Architectures

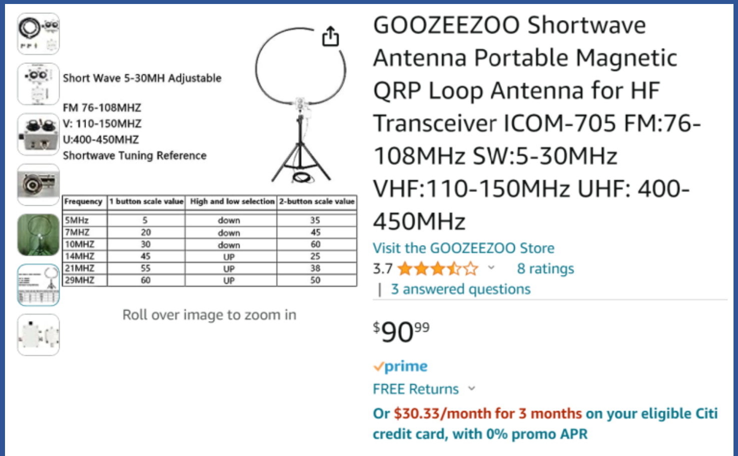
See Radio Design 101 Series, Final Epilogue

Prototype
Q-enhanced LNA
(Q = 500)

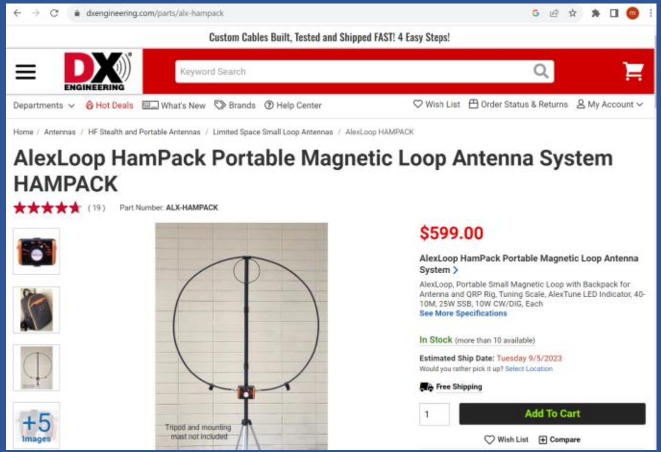




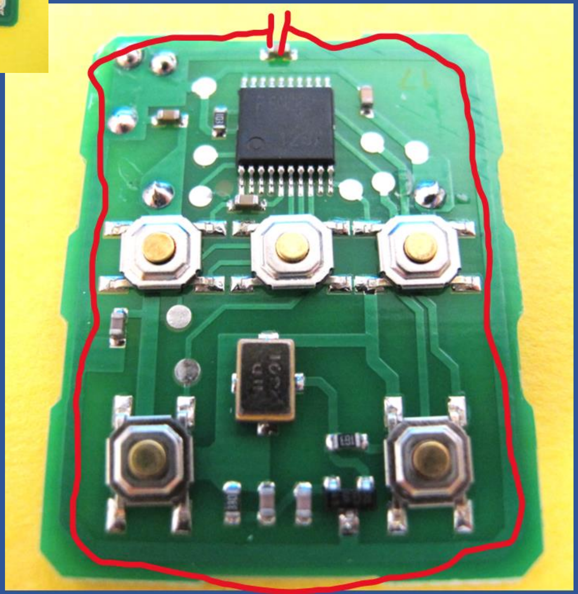
High-Q Small Loop Antennas



https://www.amazon.com/dp/B0BPD2PQF1

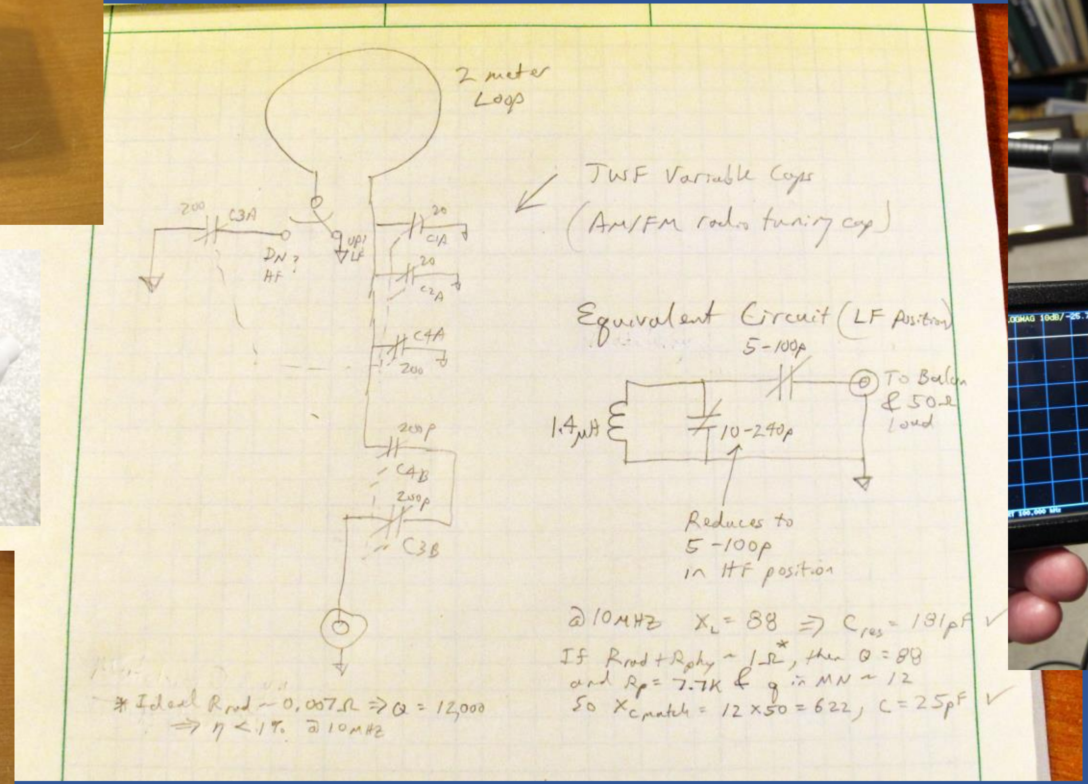


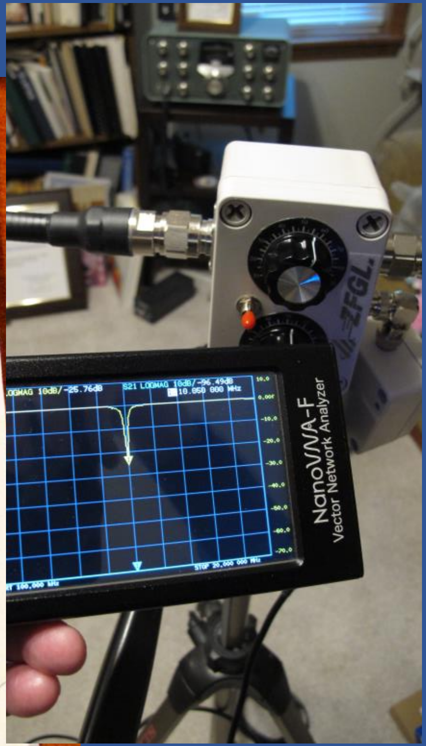
https://www.dxengineering.com/parts/alx-hampack



Loop on PCB inside of automobile key fob

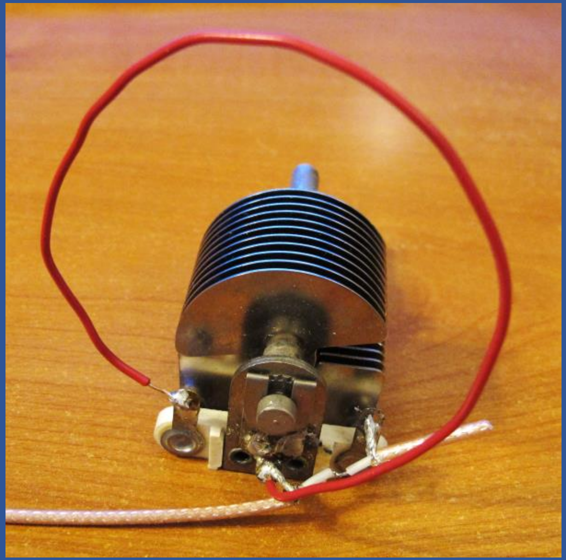
HF Band Small-Loop Design



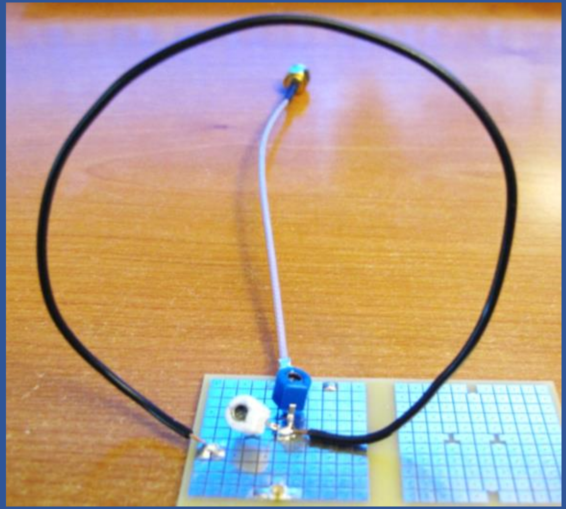


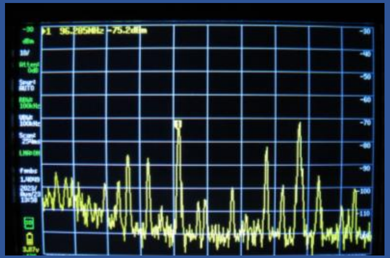
Early Prototypes of FM Tiny Loops

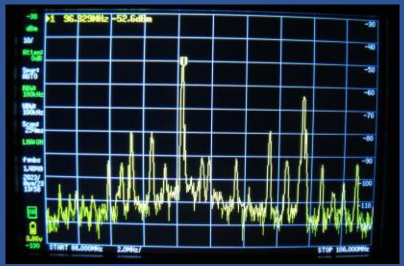
Earliest prototype of
FM Tiny Loop
(10x frequency-scaled
from HF loop antenna)

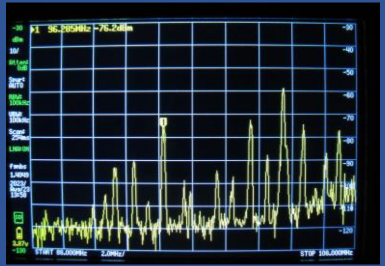


Second prototype (low-Q)

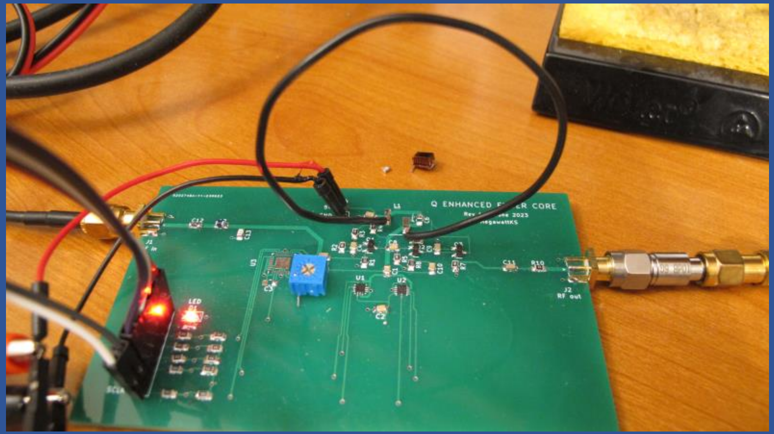


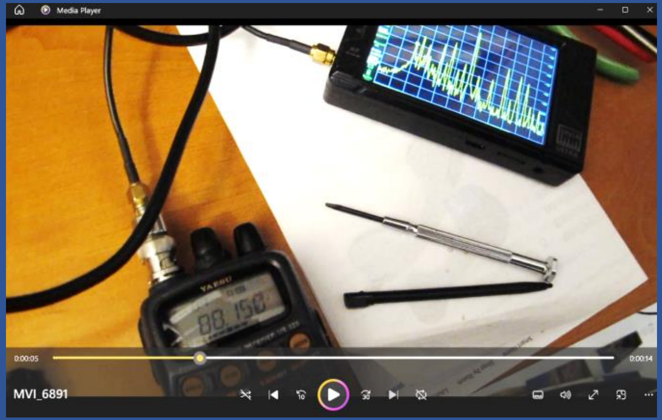






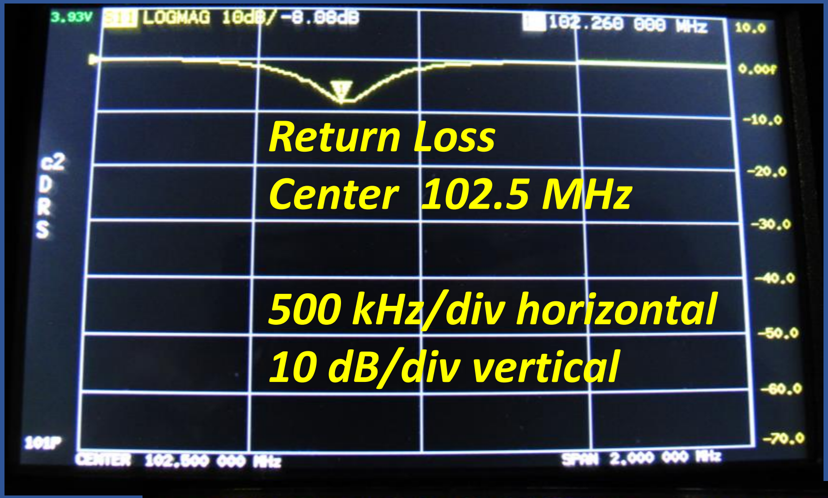
Antenna integrated with
Q-enhanced LNA

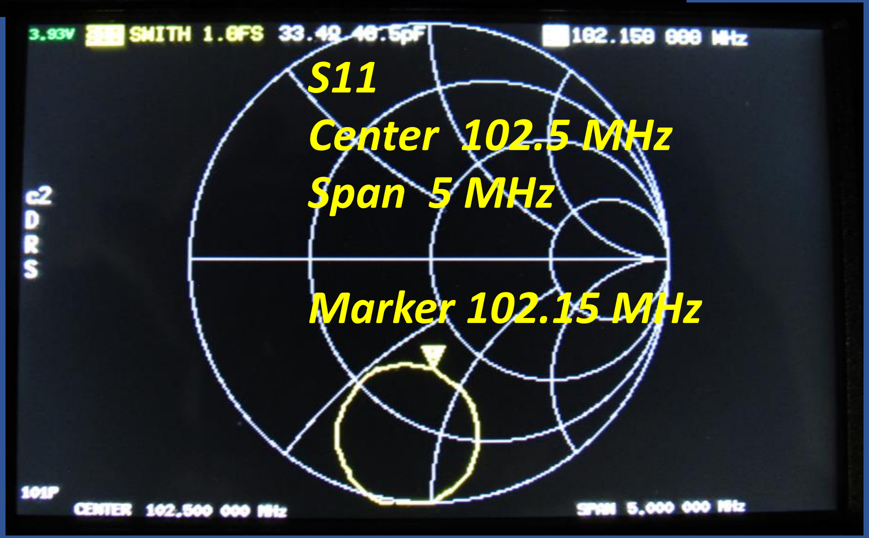


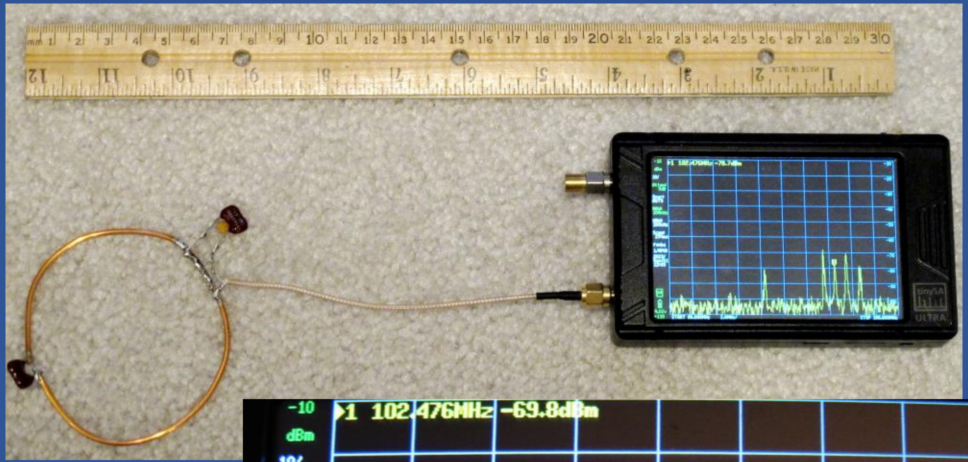


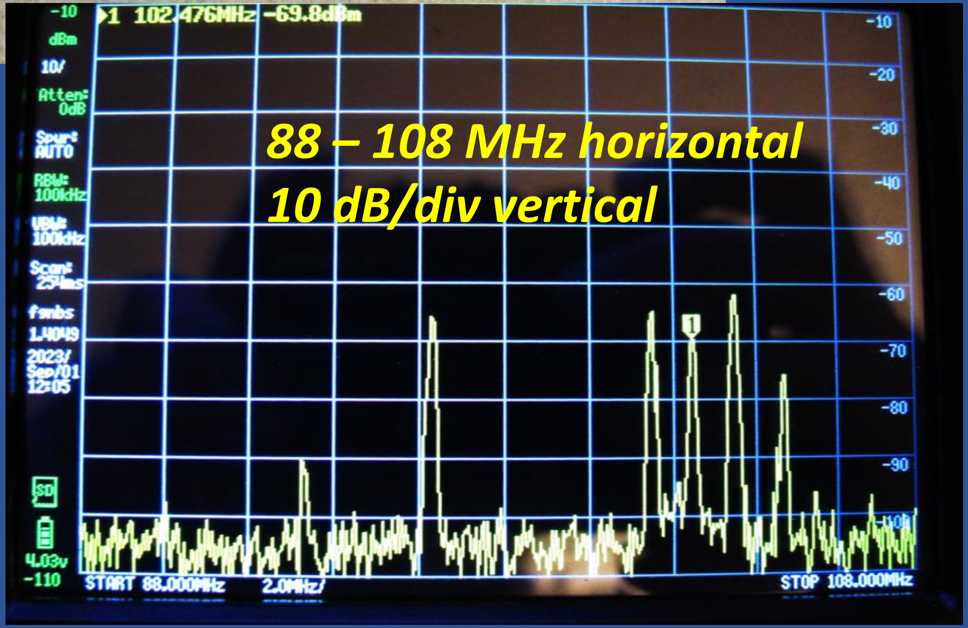
4th Prototype (High-Q Construction)

Prototype Measurements







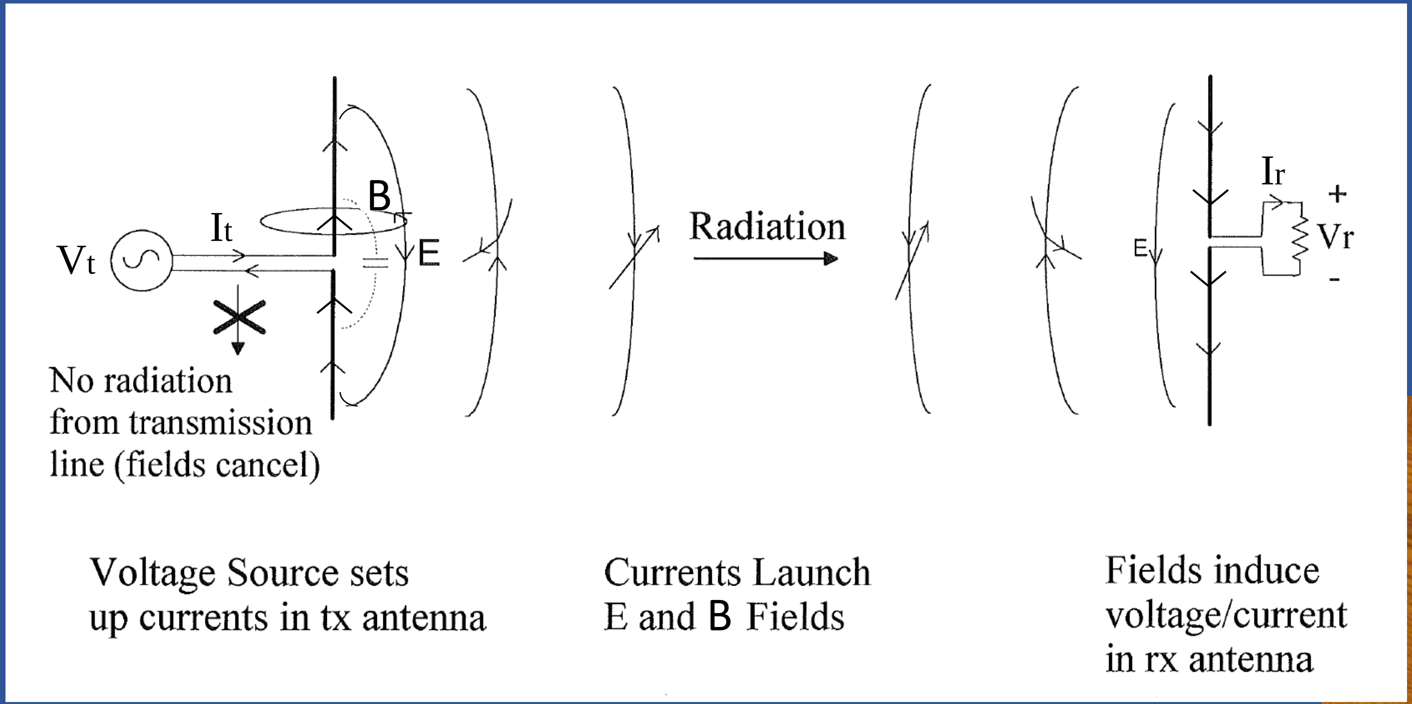


Today’s Episode

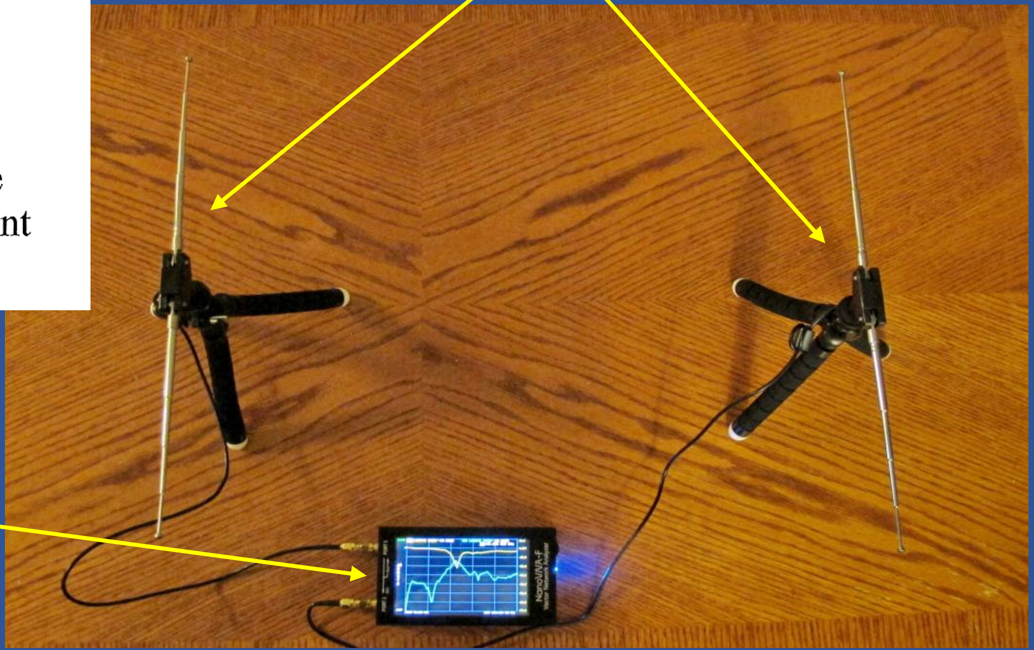
Topics

- Introduction
- Design motivations
- Evolution of the “FM Tiny Loop” design
- → Brief theory of operation
- Advantages and Disadvantages
- Summary and future directions …

Essential EM Theory (From Episode 5)



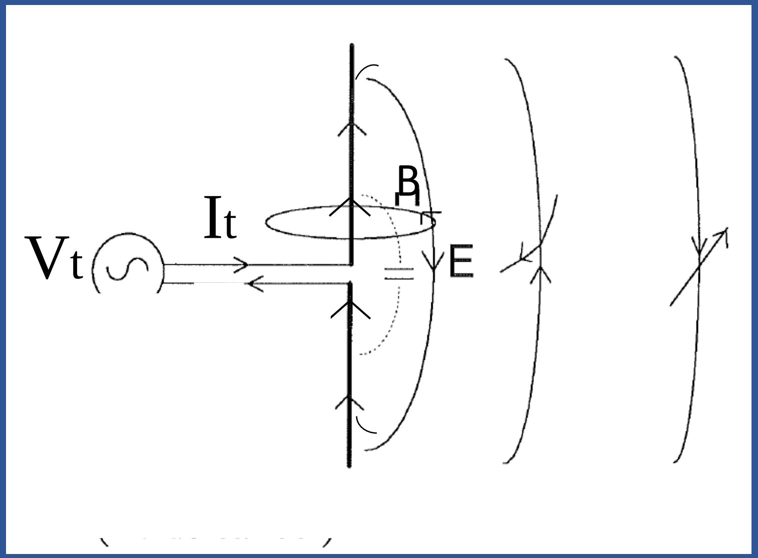
RTL-SDR Antennas

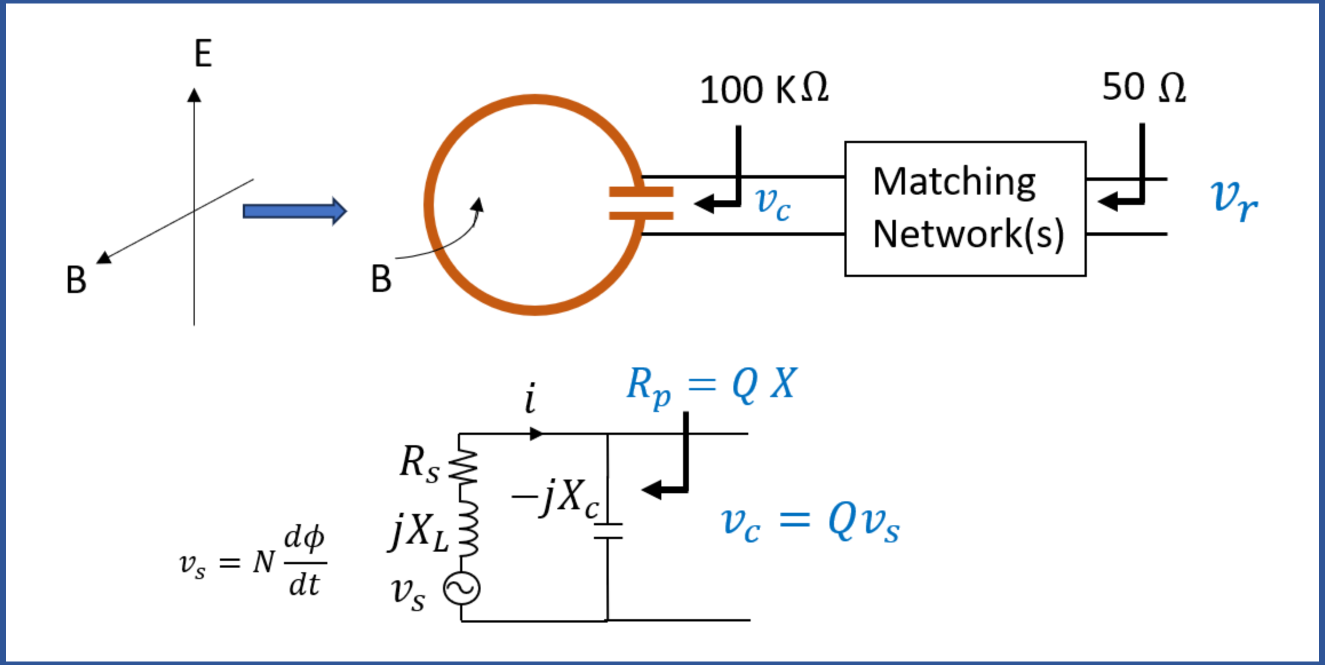


NanoVNA

(Transmitter, receiver, display)

Finding Vr at Receiver using Small Loop



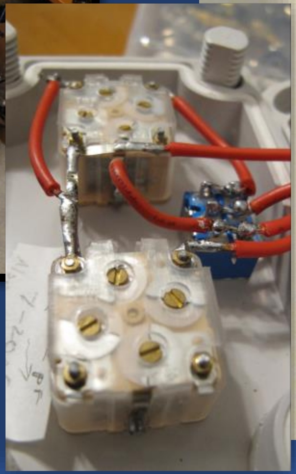


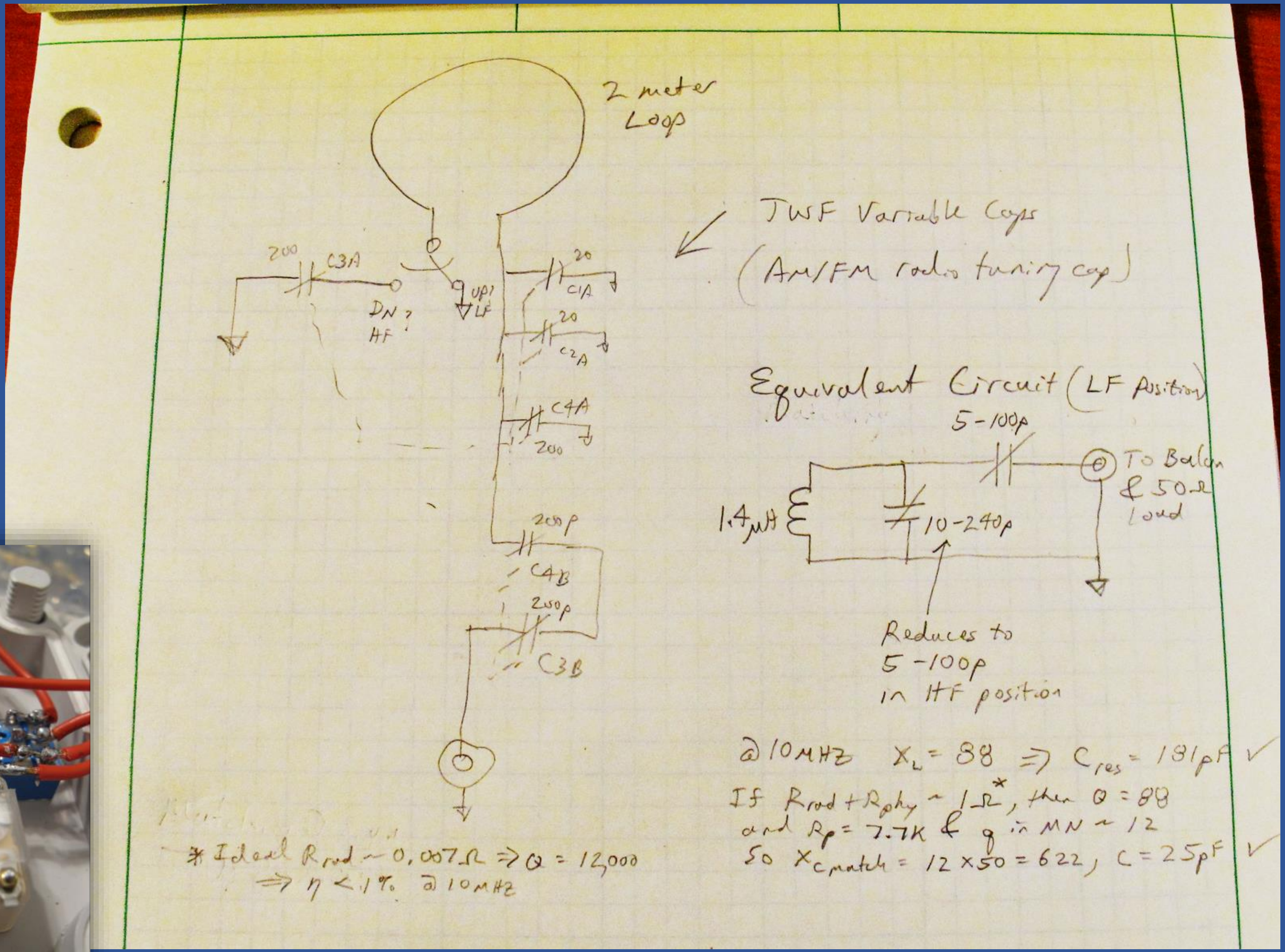
Assume X = 100, R_s = 0.1, Then Q = X/R_s = 1000 !

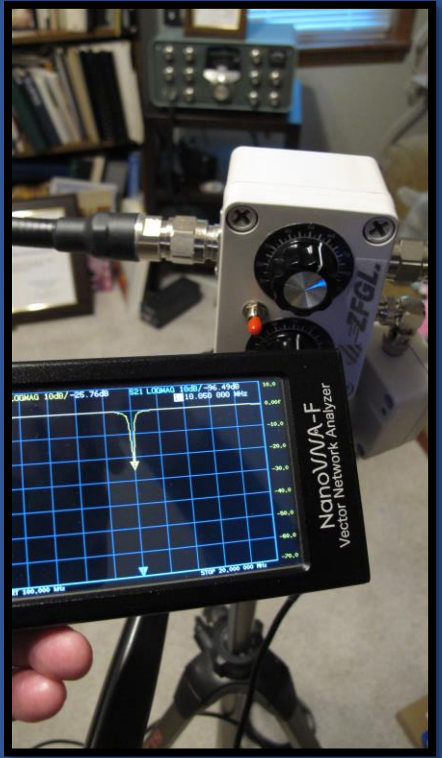
Selectivity Q = 500 when matched (=> BW = 200 kHz)

NOTE: $R_s = R_{rad} + R_{phy}$, and R_{rad} is often < 0.01, So Q > 10,000 is possible

Recall HF Small-Loop Design







10x Scaling from 10 MHz to 100 MHz

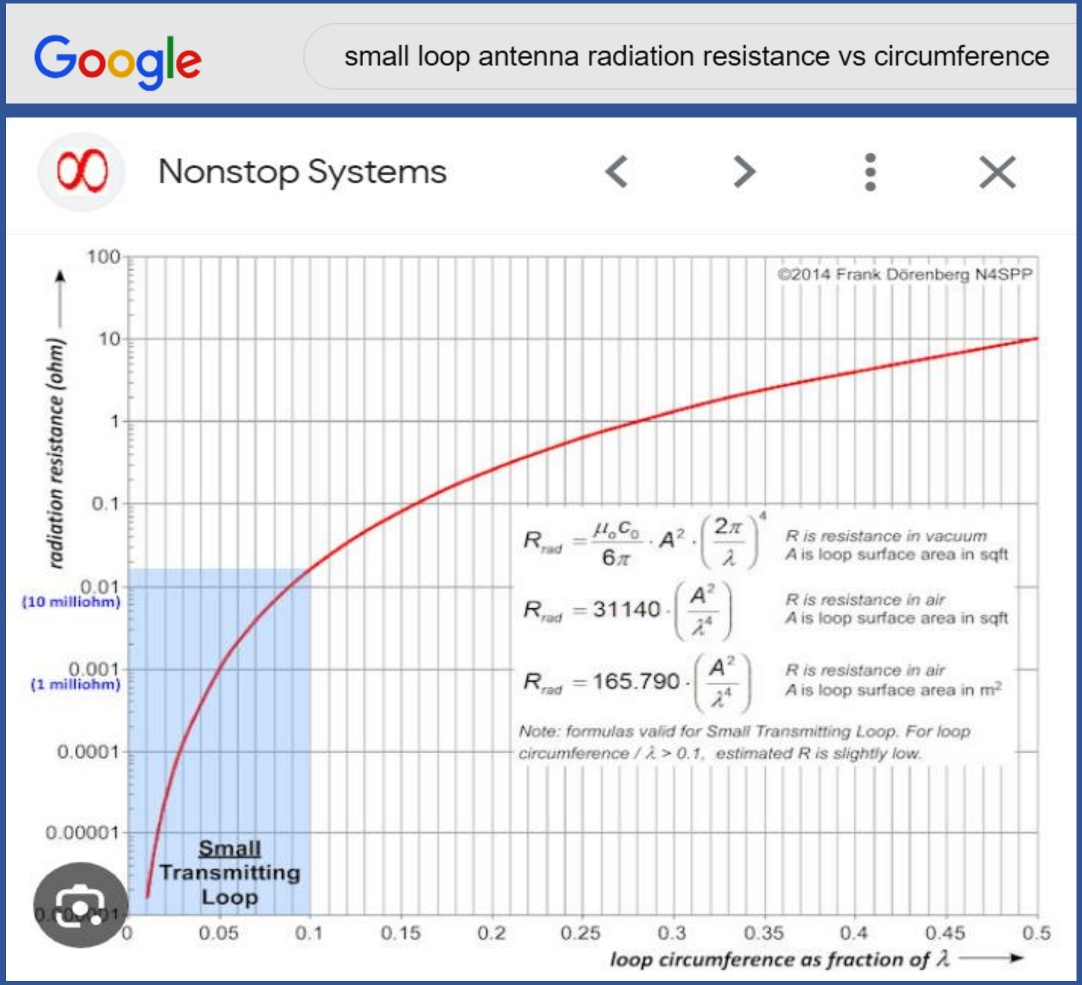
Circumference: 2.2 m -> 22 cm
Fraction of lambda: 0.075

Inductance: 1.6 -> 0.16 uH
Reactance: 100 Ohms

Radiation resistance: ~ 0.01 Ohms
$R_{rad} + R_{phy}$: 0.1 Ohms ??
LC tank Q: 100/0.1 = 1000
LC tank Rp at resonance: 100*1000 = 100K

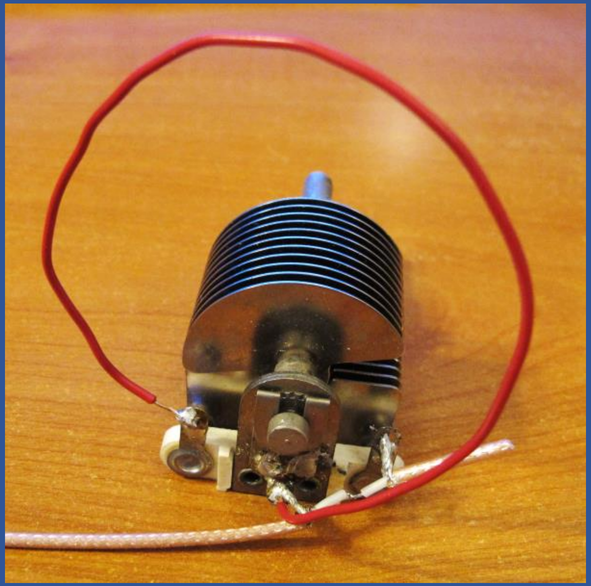
Selectivity Q (matched): 500
Bandwidth at 100 MHz: 200 kHz

Efficiency on TX: 10%
Gain on RX: ~ -10 dBd ?



https://www.nonstopsystems.com/radio/frank_radio_antenna_magloop.htm

Matching and Balun Options

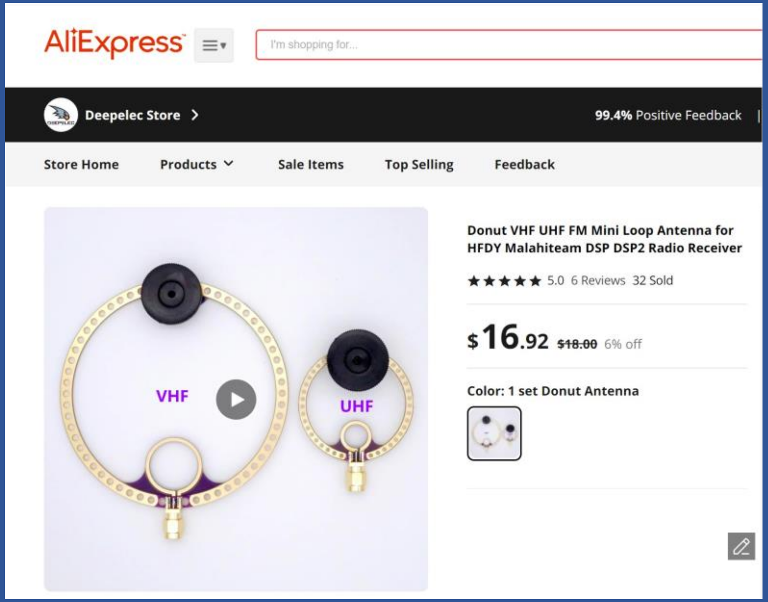


Adapted from HF loop

Needs balun to prevent formation of dipole with coax-shield counterpoise ☹

Improved. Uses tapped-L matching from 100K to 500, followed by L MN to 50

Balanced w/r/t coax shield, so no balun needed ☺



Possible alternative, using transformer matching like in HF Alex Loop

Low Q and/or insufficient tuning resolution ?

No balun needed ☺

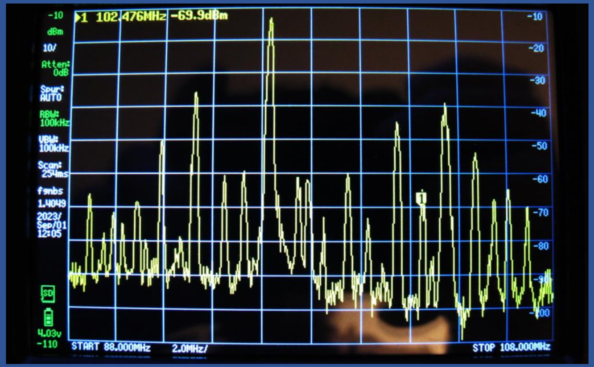
Today's Episode

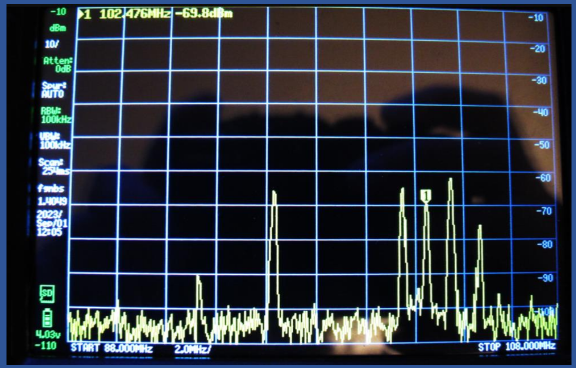
Topics

- Introduction
- Design motivations
- Evolution of the "FM Tiny Loop" design
- Brief theory of operation
- → Advantages and Disadvantages
- Summary and future directions ...

Advantages of Small Loops for VHF/UHF

- Better selectivity implemented before LNA
- Lower power circuit designs possible
- Compact dimensions compared with dipole
- Good spurious suppression for TX* mode too ☺





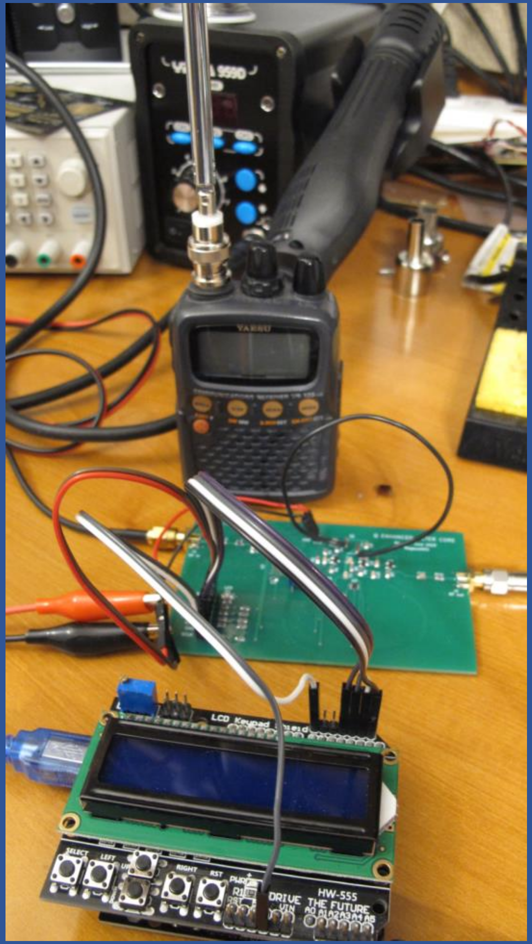
*CAUTION:
Potential RF burn and exposure-level hazards in TX mode

Disadvantages (aka "Challenges")

- Requires (very) high Q components
- **Requires re-tuning when changing channels**
- Potential EMC issues with nearby electronics ?

- Potentially lower efficiency in TX mode
- **High voltages and currents in TX mode**
- **Possible field exposure issues when transmitting?**

*CAUTION:
Potential RF burn and exposure-level hazards in TX mode

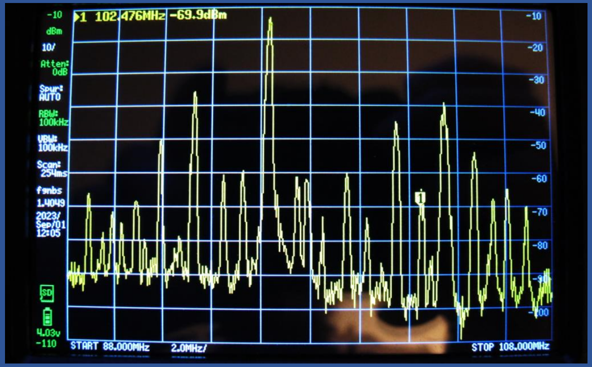


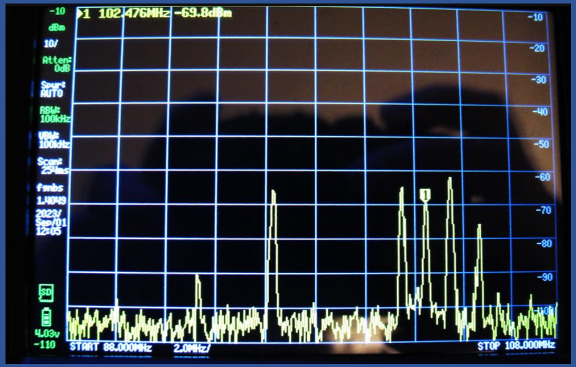
Today's Episode

Topics

- Introduction
- Design motivations
- Evolution of the "FM Tiny Loop" design
- Brief theory of operation
- Advantages and Disadvantages
- → Summary and future directions …

Tuning Plan* for FM Tiny Loop



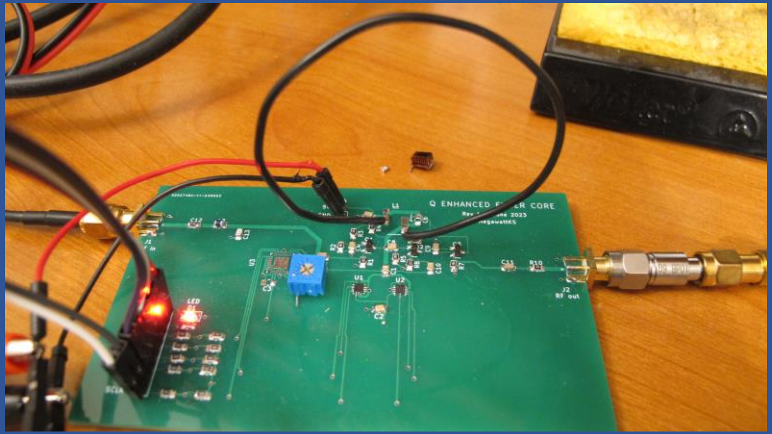


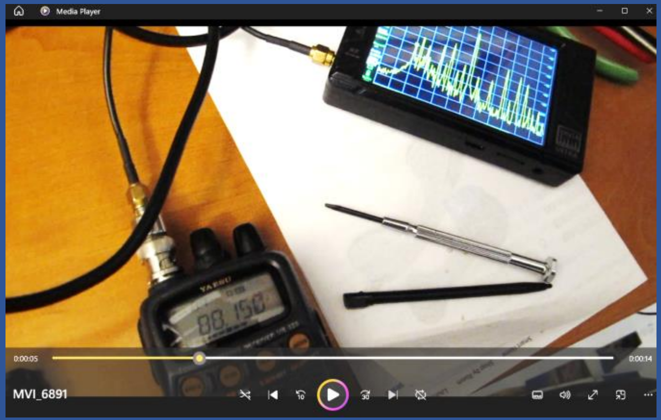
*Tuning tested 9/5/2023

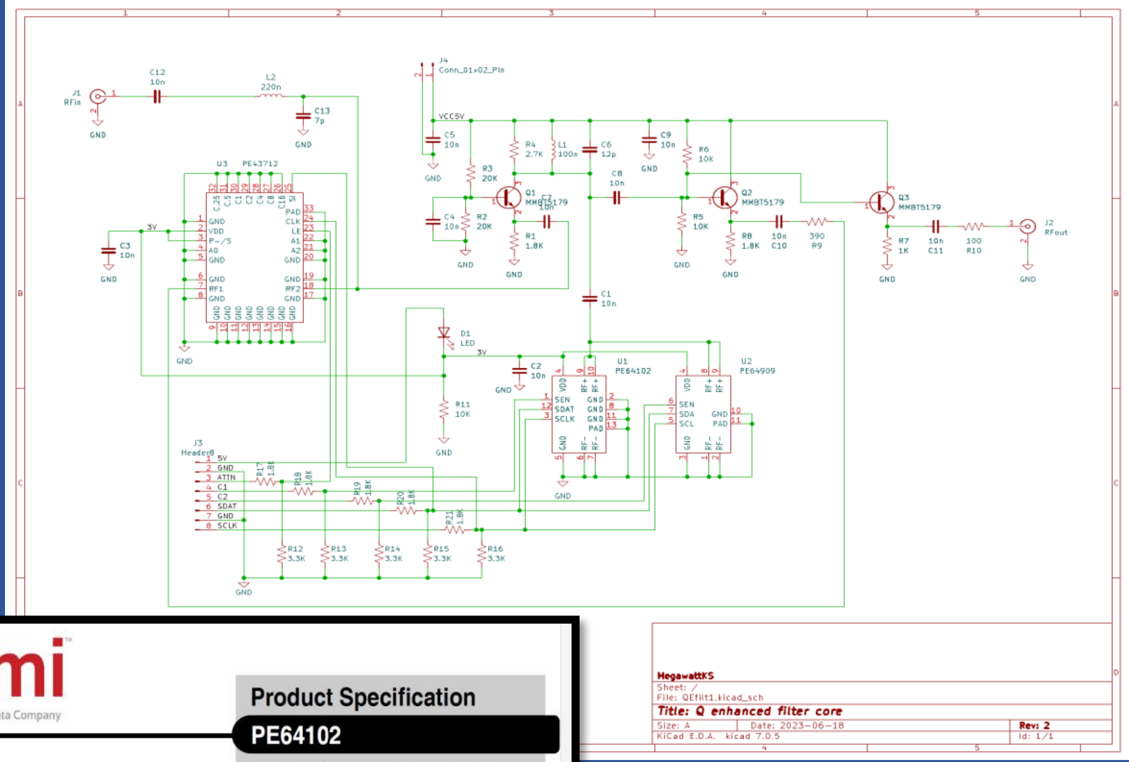
Works great ☺ !

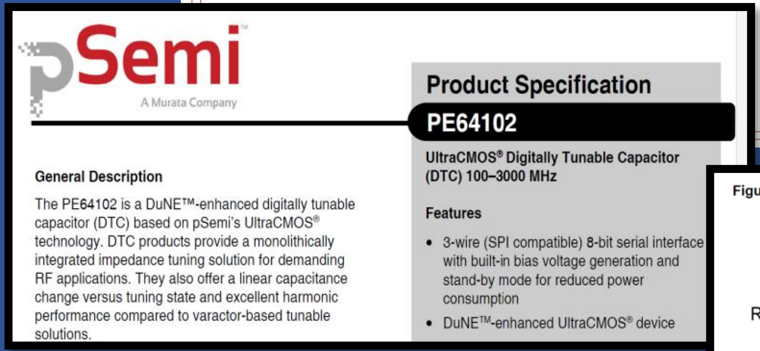
Q-Enhancement and Digitally Tuned Caps

Antenna integrated with Q-enhanced LNA








pSemi
A Murata Company

Product Specification

PE64102

UltraCMOS® Digitally Tunable Capacitor (DTC) 100–3000 MHz

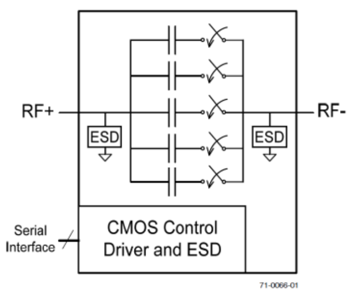
General Description

The PE64102 is a DuNE™-enhanced digitally tunable capacitor (DTC) based on pSemi's UltraCMOS® technology. DTC products provide a monolithically integrated impedance tuning solution for demanding RF applications. They also offer a linear capacitance change versus tuning state and excellent harmonic performance compared to varactor-based tunable solutions.

Features

- 3-wire (SPI compatible) 8-bit serial interface with built-in bias voltage generation and stand-by mode for reduced power consumption
- DuNE™-enhanced UltraCMOS® device

Figure 1. Functional Block Diagram



Thanks For Watching !